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**Crown-Gall Injury in the
Orchard**

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Crown-Gall Injury in the Orchard

Crown gall is a disease attacking such a large number of host plants that much work will be required to determine the extent of injury to each. It will be necessary to consider the losses from two standpoints—the percentage of host plants attacked, and the injury done to each host after it is attacked. It is evident from a review of the work already done that some kinds of plants are rarely attacked and others frequently; and that when attacked some are very seriously damaged while those of other species remain practically normal except for the presence of the gall itself. Unfortunately this state of affairs is not sufficiently recognized and there has been a tendency to assume that because crown gall is very destructive to one host it is equally so to others. This is particularly true of fruit trees. Early work established the fact that certain stone fruits when attacked by crown gall seldom make good orchard trees, and this has evidently influenced many writers to make statements applying this fact to orchard trees in general, regardless of species.

THE DISEASE

Until a few years ago it was difficult to define crown gall sharply from some other malformations. The cause was unknown, notwithstanding the fact that a great deal of work had been done on the subject. Since the publication of a paper by Smith and Townsend (15) in 1907, demonstrating that the disease is produced by a bacterial organism (*Bacterium tumefaciens* Sm. and Town.), we class as crown gall all abnormal growths in plants that are caused by that organism.

In general these abnormalities are of two kinds—true galls on roots, crowns, or stems, and “hairy root,” a condition in which unusual tufts of fine roots are produced, often at the expense of the main anchor roots. Confusion has arisen because the callus that forms in grafting and budding has a superficial resemblance to crown gall in early stages, and because unfavorable conditions of temperature and moisture may stimulate the growth of masses of fine roots much resembling hairy root; but the final distinction should be made henceforth on the causative agent, not on the symptoms alone. Unfortunately we have not yet found a method of mak-

ing rapid examinations of nursery stock for the bacterial organism and can profitably make such examinations only in rare cases.

EFFECT ON DIFFERENT HOSTS

The crown-gall organism appears able to attack a wider range of host plants than any other plant parasite. Smith, Brown and Townsend (16) have produced typical symptoms by inoculating many different species of plants. Doubtless further work along this line would show that many others are susceptible also, as only a small proportion of those inoculated under the most favorable conditions proved immune. Horticulturists have reported the disease more or less serious under field conditions on nearly all fruit trees, shrubs, and vines, and some damage is being done to vegetables and field crops. Some shade trees are also badly galled.

The authors of this bulletin have made a close study of the injury done to apple trees by the disease, but as injury to a host plant is a relative matter we will review briefly for comparison the reports of other workers on injury to different fruits. This will also show the danger in making general statements concerning the injury done without specifying the host. Only a few of the many references will be cited, but these all appear to be based on actual field observations by their authors.

INJURY TO ALMOND ORCHARDS

Toumey (21) reported that crown gall was highly destructive to almond trees, due in part to the fact that the large galls die and slough off and a destructive rot sets in at the wounds thus made. An orchard of forty acres of large trees of bearing age was so badly damaged that the trees were cut down and burned.

INJURY TO PEACH ORCHARDS

Toumey (20) has shown that peach and related trees are very seriously affected. If bearing trees have large galls on one side of the crown, the effect is shown in the condition of the tops on that side. Badly diseased trees may live for some time but seldom bear.

Bailey (2) states in reference to the peach that "trees thus affected stop growing and assume a yellowish and sickly look."

Selby (12) expressed his belief that peach trees affected with crown gall when transplanted will never come to profitable bearing. This belief was based partly, but not entirely, on personal

observation of an orchard of two hundred trees affected when set. This orchard was grubbed out as worthless when the trees had been set seven years, while nearby orchards of healthy trees were in profitable bearing.

Taft (19) states that peach trees affected with gall at the crown will make an unsatisfactory growth even if they live.

INJURY TO PLUM ORCHARDS

Paddock (11) published a figure of a six-year-old plum tree of which he says, "This tree was undoubtedly attacked in the nursery, and the continued growth of the gall so interfered with its nutrition that it was able to make but a feeble growth and was nearly dead when dug."

C. O. Smith (14), discussing the effects on stone fruits in California, says, "There are many almond, peach and prune orchards that today are unprofitable because of this disease."

INJURY TO VINEYARDS

Hedcock (7) in extensive field observations on many varieties of grape-vine, especially in the Southwest, found that in general this vine suffers severely as a result of crown-gall infection. Often the vines die back to the site of the gall, due in part to decay setting in at that point, and in part to loss of moisture through the wounds made by cracking and sloughing of the gall tissue. While the vines are seldom killed outright by the disease, they are stunted, deformed, and made so unprofitable that many thousands are removed. Some varieties, however, resist the disease much better than others.

INJURY TO BLACKBERRY PLANTINGS

Lawrence (10) and others have reported a serious form of crown gall on the canes of blackberry that causes them to split open. It may even attack the petioles and veins of the leaves. It is especially destructive on certain varieties.

Jarvis (9) states that as a result of galls on the crowns the canes become sickly in appearance and frequently break off.

INJURY TO RASPBERRY PLANTINGS

Lawrence (10) has observed that crown gall damages the raspberry even more than the blackberry.

Selby (13) states that crown gall is one of the most destructive

diseases of raspberry, resulting in the destruction of bearing canes. He leaves a little doubt, however, whether his statements refer entirely to crown gall or in part to galls caused by "eel-worms."

According to Barss (3) considerable damage results from crown gall on raspberries, blackberries, and loganberries.

From a study of the literature it is quite clear that plant pathologists and horticulturists all over the country are almost unanimous in their testimony that crown gall, under field conditions, does serious damage to stone fruits, grapes, blackberries, and raspberries. Our own field observations on the peach, blackberry, and raspberry coincide with these reports. We have had little opportunity to study the disease on almond and grape.

INJURY TO APPLE ORCHARDS

When we turn to a consideration of the effects of crown gall on apple trees standing in the orchard, the evidence of different workers is rather conflicting.

Hedgcock (8) brings out this fact clearly and the reader is referred to his bulletin for a review of the work up to 1910. Hedgcock himself, in the same bulletin, reports some general field observations and a somewhat detailed study of crown gall in four experimental orchards in which diseased and healthy trees had been set. The records on the development of the trees and of the disease were taken at intervals varying from one to six years. The experiments were seriously marred by a fire that swept through three of the orchards, but some valuable data were obtained. A little larger percentage of the crown-galled than of the healthy trees died in the orchards during the first two years after planting. On the other hand, in comparison with the healthy trees, a little smaller percentage of those having the hairy-root form of the disease died. In growth and general vigor after six years practically no difference between healthy and diseased trees could be observed. Careful measurements, however, showed that the diseased trees were a little smaller in diameter. Very little attention appears to have been given to the development of the root system.

More recently Back (1) has reported on orchard experiments begun by the Crop Pest Commission of Virginia in 1906. It is stated that, owing to changes in personnel, important notes were lost or were never taken, but some notes were published, together

with an extensive series of photographs of the roots of crown-galled and healthy trees. One series was taken at the time the trees were set and another of a portion of them after they had grown in the orchard for six seasons. Especial attention was given to the condition of the root systems, of which the author says, "It will be seen that no good root systems have developed during the past six years on the dug trees." This statement is fully justified by the illustrations published.

Many nurserymen have contended very stubbornly that crown gall is not infectious and that it is to be looked upon as a blemish and not a disease at all—merely an excessive development of callous tissue at the unions made in grafting and budding, particularly budding, and that it does no permanent injury to the trees. Unfortunately support of these contentions has been given by Hedgcock (5), who from his studies submitted the following conclusions:

"Soft crown-gall is rare, and may be related to the gall of the stone fruits. It may be slightly contagious. Hard crown-gall is related to callous formation, of which it is probably a pathological form. It is favored by stiff, heavy soils. The hairy root is a very peculiar disease, if it can be called one, with some physiological phenomena which separate it from true diseases. Cuttings from hairy-root seedlings root very much more readily and much better than from healthy ones. It is often easy to grow trees from such cuttings, but almost impossible to grow them from normal cuttings."

From the published work on crown gall and from our own experience with this disease we are led to believe that the conflicting opinions as to the damage done to apple trees when attacked by crown gall are due to the following facts and perhaps others:

(1) From known injury to certain kinds of fruits it has been inferred that apple trees would be similarly injured.

(2) From the unsightly appearance of the malformations, combined with knowledge, recently acquired, that the disease is caused by a bacterial organism, an inference has been drawn that serious damage would result.

(3) Under orchard conditions some have not observed closely enough the damage that was actually being done.

(4) Some have attributed to crown gall damage that was being done by other agencies, as nematodes, wood-rot fungi, unfavorable soil, etc.

(5) From the fact that some apple trees known to be affected

have made a good growth for a few years after being set in the orchard, it has been inferred that no appreciable damage would result even after they came into bearing.

(6) Not enough consideration has been given to the location, size, and character of the galls, nor to the condition of the root system aside from the galls.

(7) A poor development of the root system as a result of crown gall has often escaped notice.

(8) In different soils crown-galled trees behave differently.

EXPERIMENTAL WORK BY THIS STATION

During a time when shipments of nursery stock into Montana were very heavy, the controversy with the nurserymen as to the ultimate effect of crown gall upon apple orchards became so strong that it was decided to set out an orchard of affected and healthy trees and study, year by year, the effect of the disease upon the trees. This orchard was set out upon the horticultural substation grounds near Corvallis in the Bitter Root Valley in western Montana.

The following data will be of value in showing the conditions under which the experiment was carried out.

Source of stock—A prominent nursery in the Middle West.

Date of setting—May 20, 1910.

Varieties—Anisim, Hibernial, Hyslop (crab), Longfield, Northwestern (Greening), Oldenburg (Duchess), Patten, Wealthy, Whitney (crab), and Wolf River—ten in all.

Number—Twelve healthy trees and twelve diseased ones of each variety—a total of 240.

Age—Two years, i. e., grown from root grafts made in 1908.

Condition—All vigorous and thrifty.

Plan of planting—Trees set in rows, eight feet apart each way. The diseased trees were in a solid block, ten by twelve rows, and the healthy ones in a similar block adjoining it on the north (fig. 1).

Soil—A light sandy loam, underlaid at a depth varying from sixteen to thirty inches with a lime and clay hard pan. The land has a gentle slope to the south.

Detailed notes were taken on each tree before it was set in the orchard. Every diseased tree had at least one gall on the crown;

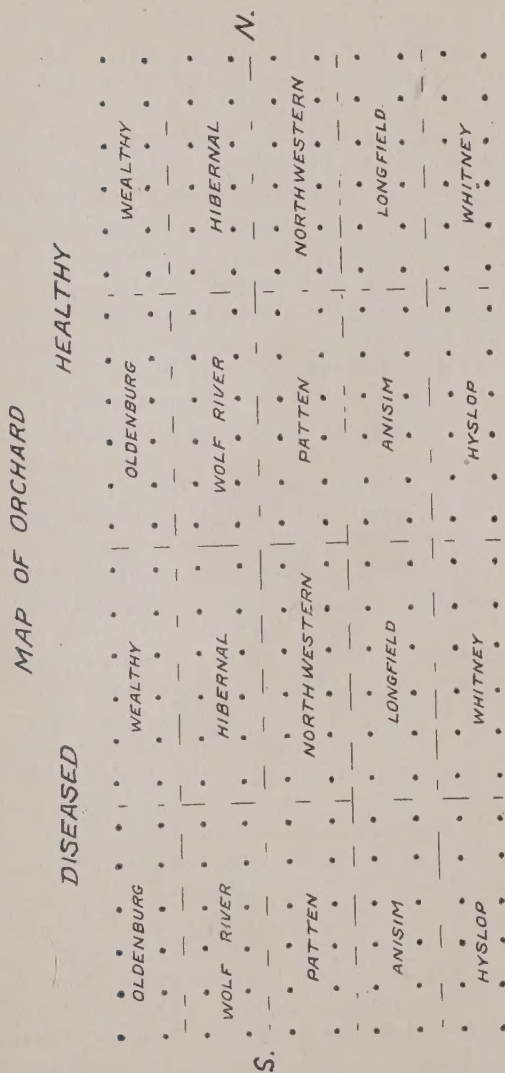


FIG. 1. Map of crown-gall orchard in the Bitter Root Valley, showing varieties, and relation of diseased to healthy trees.

most of them had two or three, and a few had four. These varied in size from one to two and one-half inches. As a rule they extended from one-third to one-half of the way around the crown, but a few nearly or quite encircled it. Nearly all had a few small galls on the lateral roots. Nearly all had more or less of the hairy-root form of the disease, which on some was very abundant. In other words, these trees all showed the disease in a well-developed condition. Practically all forms of the disease were well represented excepting the aerial type. In one respect the trees were not quite representative of crown-gall stock as it is received by orchardists when no restrictions are placed upon the sale of such stock, in that all trees that had developed hairy root at the expense of good, strong anchor roots had been culled out at the nursery. There was not a single tree of the kind we have often seen in commercial shipments in which the whole root system consists of a mass of hairy roots with no large, strong ones. Every tree in this lot had good, strong roots.

The trees were carefully set and were well cared for by the superintendent of the substation. Only a very small proportion of them died as a result of transplanting from the nursery.

In September, 1912, notes were taken on all the trees. In general, the growth of both the healthy and the diseased trees had been very good; indeed there was no apparent difference between the corresponding varieties in the two blocks in the matter of tops and trunks. Half of the trees were then dug up and the roots examined. For this purpose every other row diagonally was taken. At this time a marked difference was apparent in the root systems of the healthy and the diseased trees, those of the former being in almost every case stronger. Reference to the original notes showed that none of the galls excepting a few of the smaller, softer ones had disappeared but that most of them had enlarged considerably.

During the summer of 1915 blight was severe in the Bitter Root Valley and these young, vigorous trees suffered considerable injury. Some were killed outright, while others were so badly injured that practically the whole top had to be removed. In the spring of 1916 all the killed and badly blighted trees were pulled out and the difference between the root systems of the diseased and the healthy trees was most apparent. A horse was used for this work and in most cases he was unable to remove the healthy

trees with a single pull but had to pull repeatedly this way and that to break off the roots. On the other hand, very little trouble was experienced with the diseased trees. With a few exceptions the horse pulled them out at a single attempt, sometimes with very little effort indeed.

In November, 1917, final notes were taken and the last of the trees were removed as it was necessary to use the land for other experimental work. At this time, after a growth of eight seasons, few of the galls had disappeared entirely and most of them were still growing. Some were several inches in diameter. In some cases there was a general enlargement of the diseased crowns to more than twice the circumference of those of any of the healthy trees. Very few new galls, however, had been formed either on the crowns or on the roots. The hairy-root condition was very little in evidence and in most cases it could scarcely be found. So far as we could tell none of the trees had died as a direct result of crown gall, though the havoc wrought by blight so complicated matters that we can not say positively that crown gall had killed none. No very great difference was apparent between the tops of the diseased and the healthy trees, though a good observer could notice that the healthy ones had made a little better growth. The root systems of the diseased trees, however, were very inferior. The ac-

Table showing circumference in inches of healthy and crown-galled trees after growing in the orchard for eight seasons.

Variety	Healthy				Crown-galled			
	Number of trees	Largest	Smallest	Average	Number of trees	Largest	Smallest	Average
Anisim	5	14.25	13.00	13.60	4	12.75	10.75	11.75
Hibernal	4	16.00	15.00	15.56	6	11.25	10.00	10.67
Hyslop*	0	.....	.....	.....	0	.....	.....	.....
Longfield	3	13.75	12.25	13.00	5	12.75	8.75	11.00
Oldenburg	5	13.50	11.75	12.60	6	12.00	10.00	11.00
Northwestern +	6	15.75	11.75	13.13	4	14.50	12.75	13.44
Patten	5	12.50	10.75	11.60	3	11.25	8.50	10.00
Wealthy	2	12.50	12.00	12.25	3	13.00	12.00	12.42
Whitney*	0	.....	.....	.....	0	.....	.....	.....
Wolf River	6	16.50	10.00	13.21	4	13.75	11.25	12.70
Entire block ...	36	16.50	10.00	13.12	35	14.50	8.50	11.54

*All trees of these two varieties were removed prior to 1917.

companying table shows the number of trees of each variety that remained to be dug out at this time and the relative circumferences of the trunks twelve inches above the surface of the ground.

From this table it may be seen that with the exception of Northwestern Greening and Wealthy the dwarfing effect of the crown gall was quite apparent. In Northwestern Greening the tops of the diseased trees were fully as good as those of the healthy ones. The Wealthy trees were so reduced in number by blight that a fair comparison was hardly possible. In no case was a tree so markedly dwarfed as one sometimes finds, apparently as a result of crown gall, in a bearing orchard. The reduction in size, however, is much more pronounced than that reported by Hedgcock (8) for a similar experiment carried out in Missouri. The average reduction in **circumference** in the Montana experiment was 1.58 inches. The average reduction in **diameter** in the Missouri experiment was 0.29 inch. We preferred to measure circumferences rather than diameters because the irregularities in trunks would have made measurements of the diameter rather uncertain.

The most striking thing brought out by this experiment is the greatly disturbed balance between the tops and the roots of the affected trees. Doubtless this would have been still greater had not those with no strong anchor roots been culled out and discarded before shipment from the nursery. Whether or not the weakened root systems would have resulted in more serious injury to the tops or the crop after the trees came into heavy bearing can only be surmised. If not, it is of no significance unless the trees have a greater tendency to loosen in the ground under the influence of the high winds. In the sheltered location of this orchard there was no such tendency.

All things considered, it is safe to say that the increased value of the healthy trees over the galled ones at the time they were removed was much more than the original cost of the nursery stock.

INFLUENCE OF CHARACTER OF DISEASE ON ULTIMATE EFFECT UPON THE APPLE TREE

Under the name crown gall we now include all abnormal growths caused by the bacterial organism, *Bacterium tumefaciens*. This excludes all gall formations due to nematodes, woolly aphids or other insects, or any other form of life excepting the organism

just named. The disease, however, shows several manifestations.

Following the usage of certain nurserymen, Stewart, Rolfs and Hall (18) first published the term "hairy root" to describe that form of the disease in which the chief manifestation is an abnormal mass of fibrous roots growing in dense clusters. They regarded it as a distinct disease, though with our present knowledge we can recog-



FIG. 2. Hairy-root form of crown-gall, of moderate severity, showing poor development of strong anchor roots.

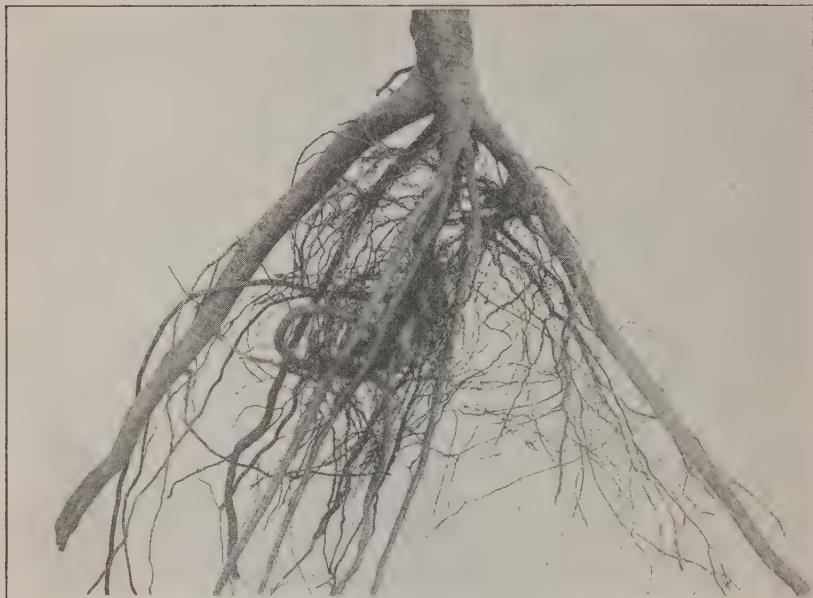


FIG. 3. Mild case of hairy-root on tree with many strong roots.

nize in their Plate XXIII flat galls where the tufts of roots attach to the crown.

Hedgcock (4) accepted this view that crown gall and hairy-root are two distinct diseases. He classified crown gall as "hard" and "soft," the former more permanent and the latter more likely to rot off. In a later paper (5) he subdivided hairy-root into several different kinds.

An aerial development on trunks and branches has been described by Hedgcock (6) and others.

Smith (17) and his assistants have furnished convincing evidence that the so-called hard and soft forms of crown gall and the hairy root are all caused by the same organism and must be regarded as different manifestations of one disease. They submit the hypothesis that the kind of tissues stimulated by the organism to abnormal growth will determine whether the resulting gall will be hard or soft.

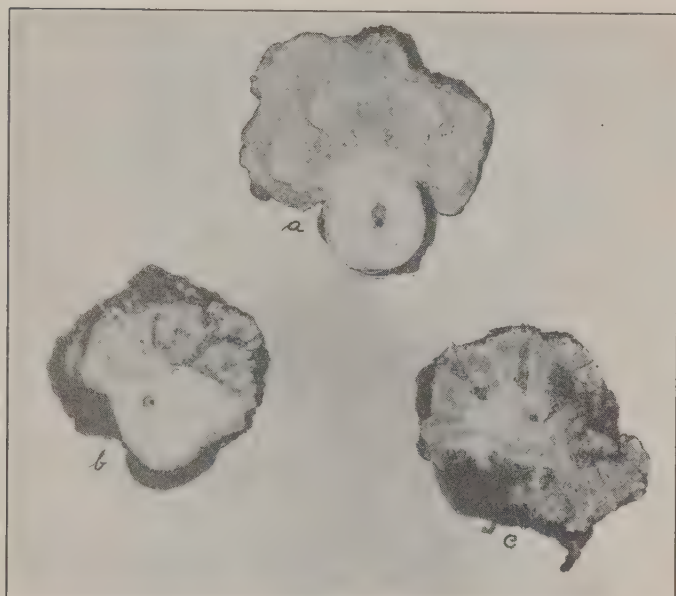


FIG. 4. Cross-sections through three crown-galls: (a) gall extends only one-third around root; (b) gall extends more than half way around root; (c) gall entirely girdles root. The black dot in each case marks the original center or pith of the root. (Natural size.)

In the apple the degree to which the tree will be injured when attacked by crown gall will be determined partly by its environment after being planted—especially the character of the soil—but also by the character of the disease itself. If the hairy-root form is developed at a sacrifice of large anchor roots (fig. 2), a poorly rooted tree will be the result. If, on the other hand, some tufts of hairy root are developed on an otherwise good root system (fig. 3), this is relatively unimportant. If there are large galls on the crown they are of more importance than if on lateral roots, especially the smaller ones. Galls that are attached by a narrow neck, like that shown in figures 4a and 5, or narrower, are much less injurious than those that extend nearly or quite around the crown or root (figs. 4b, 4c, and 6).

The principal damage done by the galls seems to be an interference with the normal conduction of water and food, and a mechan-

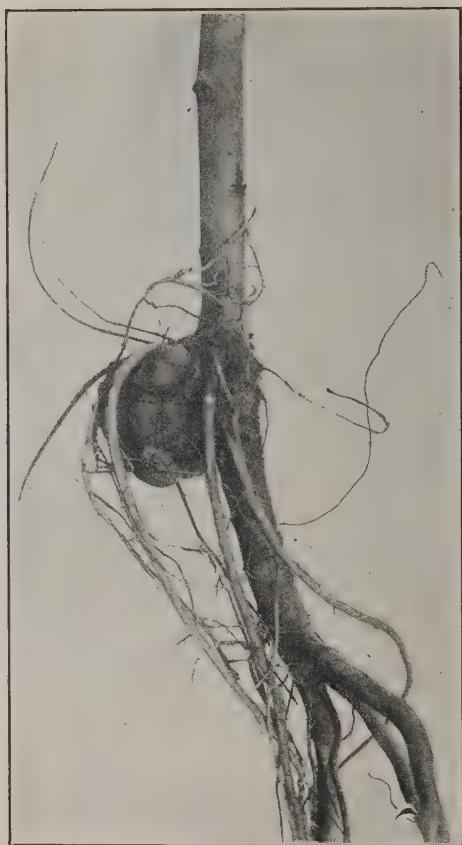


FIG. 5. Crown-gall with relatively narrow attachment to crown.

ical weakening of the crown or root at the point of attachment. When pulling out affected trees with a horse, it was not unusual for them to break across through a badly galled crown, the break usually taking place through the upper portion of the gall.

In addition to the experimental work reported in this bulletin, we have occasionally observed very much dwarfed apple trees in bearing orchards much older than the one at the horticultural sub-station. When dug up and examined, certain of them showed an



FIG. 6. Crown-gall nearly girdling the crown.

exaggerated development of crown gall with a reduced root system and no other tangible cause of the dwarfing. We naturally assign crown gall as the cause of the dwarfing.

CONCLUSIONS

(1) It is not safe to assume from damage done to one host that like damage will be done to another host.

(2) Apple trees attacked by crown gall are much less injured by it than are the almond, peach, plum, grape, blackberry, or raspberry.

(3) Some varieties of apple are more injured by the disease than others.

(4) Apple trees affected with crown gall and planted in the orchard will seldom make as good trees as those unaffected. The damage done will vary from practically nothing up to a condition of serious dwarfing.

(5) The dwarfing is much greater in the roots than in the parts above ground, but as the roots are not visible this fact has been generally overlooked.

(6) The ultimate injury will be affected by at least two factors—environmental conditions and character or type of the disease.

(7) Hairy root in so far as it develops at the expense of strong anchor roots is very important. This form of the disease on an otherwise well-developed root system is much less important.

(8) Galls on the crown are more serious than those on the lateral roots, especially on the smaller ones.

(9) Galls damage the trees by interfering with food conduction, by mechanically weakening the crown and roots, and by paving the way for other diseases.

(10) As a general proposition it would be better for an orchardist to pay the regular price for healthy stock than to plant crown-galled stock if he could get it free.

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